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PROGRESS REPORT: LONG-TERM BENTHIC MONITORING AND ASSESSMENT PROGRAM FOR THE MARYLAND PORTION OF CHESAPEAKE BAY (JULY 1986 -- OCTOBER 1987) VOLUME I -- TEXT

MAY 1988

MARYLAND POWER PLANT RESEARCH PROGRAM

MARYLAND DEPARTMENT OF NATURAL RESOURCES
MARYLAND ENERGY ADMINISTRATION

As Secretary of the Maryland Department of Natural Resources, I am convinced that public support of DNR's mission is essential if we are to restore the State's once bountiful natural resources, especially the Chesapeake Bay, to the level which earned the title "America in Miniature." The information in this publication is designed to increase your understanding of our program and of Maryland's natural resources.

Torrey C. Brown, M.D.

PPRP-LTB/EST-88-1

PROGRESS REPORT: LONG-TERM BENTHIC MONITORING AND ASSESSMENT PROGRAM FOR THE MARYLAND PORTION OF CHESAPEAKE BAY (JULY 1986 -- OCTOBER 1987)

VOLUME I -- TEXT

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FOREWORD

This report, "Progress Report: Long-Term Benthic Monitoring and Assessment Program for the Maryland Portion of Chesapeake Bay (July 1986 -- October 1987)" was prepared by Versar, Inc., ESM Operations at the request of Dr. Paul Miller of the Maryland Department of Natural Resources, Power Plant Research Program, and Mr. Michael Haire of the Maryland Department of the Environment, Water Management Division, under PPRP contract numbers P64-85-02(86) and P64-85-02(87). It is a summary of the findings of the data collected during the first three years of a five year study to assess long-term responses of benthic communities to changes in water quality resulting from Bay-wide cleanup efforts, and to assess short- and long-term responses of the benthos to power plant operations.

This report is organized into three volumes. Volume I contains the text and summarizes the major findings. Volumes II and III contain Appendices A through KK and provide hard copy of the water quality data through October 1987, abundance data through June 1987, and biomass/productivity data from July 1984 through June 1985. The large number of tables and figures required to summarize and display the data distracted from the flow of the text when inserted directly. Therefore, tables and figures have been included at the end of each Chapter in Volume I.

EXECUTIVE SUMMARY

The long-term benthic monitoring and assessment study for the Maryland portion of Chesapeake Bay is jointly sponsored by the Maryland Department of Natural Resources, Power Plant Research Program (PPRP) and the Maryland Department of the Environment (MDE), Water Resources Division. These studies are an integral component of the interdisciplinary Chesapeake Bay monitoring and assessment program. Both sponsoring agencies use the study of benthic communities to evaluate existing conditions and measure changes in those conditions that result from man's activities, including power plant operations, pollution inputs, and pollution abatement. The major long-term objectives of this program are to: 1) determine the effectiveness of Baywide pollution abatement programs; 2) measure the cumulative, long-term impacts of power plant operations on Bay benthic resources; and 3) assess the status and trends for Bay water quality and biological resources. Results of this program will also provide information on the processes and mechanisms controlling Chesapeake Bay water quality and will thus help MDE develop a water quality management strategy for existing and future water quality management problems. It will provide PPRP with information required to evaluate long-term power plant effects on Chesapeake Bay living resources and to preparae a biannual Cumulative Environmental Impact Report. The information presented in this report summarizes the data collected from 1984 through 1987 (see Foreword, p. iii).

Sampling of benthic communities, sediments, and water quality was conducted from July 1984 through December 1987 at 70 stations in the Maryland portion of the Chesapeake Bay and its tributaries. Salinity regimes ranged from tidal freshwater (0-0.5 ppt) to polyhaline (18 to 25 ppt). Sediments included mud and sandy-mud in the upper Bay and most of the tributaries, nearshore sand and deepwater mud and sandy-mud in the Potomac River, and sand, muddy-sand, sandy-mud, and mud in the middle and lower Bay.

Five major benthic habitat types were recognized based on the suite of water quality and sediment parameters measured at each station. These were: 1) a high mesohaline-polyhaline mud habitat in the deep central portion of the Bay that always experienced anoxic/hypoxic conditions during summer; 2) a high mesohaline mud and sandy-mud habitat that experienced hypoxic conditions during the summer of most years; 3) a low salinity mud and sandy-mud habitat that did not experience anoxic/hypoxic conditions; 4) a high mesohaline sand habitat with relatively low sediment silt/clay and carbon content that occasionally experienced anoxic/hypoxic conditions when water having low dissolved oxygen concentrations upwelled into shallow nearshore habitats from the deep central Bay as a result of meterological events; and 5) a high and low mesohaline sand and muddy-sand habitat with relatively high sediment silt/clay and carbon content that rarely experienced anoxic/hypoxic conditions.

The region of the Bay affected by critically low anoxic/hypoxic bottom water was generally confined to water depths greater than 9-m and extended from the entrance of Baltimore Harbor to the mouth of the Potomac River, up the Potomac River to Morgantown, and up the Patuxent River to Broome's Island. During the summer of 1984, anoxic/hypoxic conditions were especially severe and extended into the lower reaches of the Patapsco, Chester, and Choptank Rivers. During the summers of 1985, 1986, and 1987 anoxia was not as severe or as persistent as it was in 1984 and did not extend into the mouths of the Patapsco, Chester, or Choptank rivers. Year-to-year variation in freshwater inflows appears to be an important factor controlling year-to-year variation in the duration and severity of summer anoxia. This natural source of variation must be estimated and accounted for before anthropogenic influences on the extent and/or duration of anoxia/hypoxia in Chesapeake Bay can be quantified.

Benthic assemblages were identified based on similarities in the species composition and relative abundance of benthic invertebrates and included: 1) a tidal freshwater/oligohaline mud and sandy-mud assemblage; 2) a low mesohaline mud, sandy-mud, and sand assemblage; 3) a high mesohaline sand and muddy-sand assemblage; and 4) a high mesohaline (deep water) mud assemblage. Tidal freshwater and oligohaline assemblages were usually segregated because they represented distinct groups of benthos as were assemblages in sand and muddy-sand habitats of the higher salinity region. These assemblages generally corresponded closely with habitat types identified on the basis of water quality and sediment characteristics, suggesting that physical and chemical characteristics are the major factors controlling spatial distribution of Chesapeake Bay benthos.

The strata identified by the analyses conducted for this study were similar to the segments recognized by the U.S. EPA Chesapeake Bay segmentation scheme except that differences between shallow and deep habitats were not recognized in the latter. However, water quality and other functional characteristics of shallow and deep habitats differ significantly. Response patterns to pollution abatement and power plant operations are, therefore, likely to be different among these strata, and we recommend that the EPA Chesapeake Bay segmentation scheme be modified to reflect the differences between shallow and deep habitats.

Historical (early 1970's - present) benthic data from the upper Bay, Baltimore Harbor, and the upper Patuxent suggest that abundances of estuarine species have increased in these regions of the Bay during recent years. These increases do not appear to be explainable on the basis of long-term salinity trends and may be related to water quality improvements associated with pollution abatement programs. In the middle Patuxent, the abundance of estuarine benthos has declined in recent years even though salinity conditions there are optimum for recruitment and growth. Factors contributing to declines in benthos of the middle Patuxent are not clear but likely contributors include: 1) changes in operations of the Chalk Point power plant (which returned to full power generation in 1982 after an extended period of reduced generation) and 2) reduction in primary productivity associated with pollution abatement programs in the upper Patuxent River. Fluctuation in the abundance of benthos in the middle Potomac appears to be almost entirely related to year-to-year variation in salinity during spring recruitment. Four major patterns of long-term variation were recognized in the mid-Bay region. These were: 1) increased abundance of high salinity species beginning in 1981-1982; 2) increased abundance of small short-lived forms adapted to living at the sediment-water interface and which brood or protect early developmental stages beginning in the mid 1970's and; 3) decreased abundance of larger, longer-lived benthos tolerant of lower salinities also beginning in the mid 1970's; and 4) stable local populations of larger, long-lived benthos in the discharge region of the Calvert Cliffs power plant even though populations of these species declined regionally. Salinity is clearly a major factor contributing to long-term changes in benthic abundance in the mid-Bay region. However, other factors are also important. For example, declines in the abundance of the larger, long-lived benthos appear to be related to the annual occurrence of low dissolved oxygen conditions.

Highest benthic biomass and productivity were consistently found in tidal freshwater/transitional and low mesohaline habitats near the zone of maximum turbidity. Large, long-lived clams were the major contributors to both biomass and production in these lower salinity habitats. In high mesohaline and polyhaline habitats, crustaceans and polychaetes were the major contributors to biomass and production. Factors contributing to spatial and temporal trends in benthic biomass and productivity are currently being evaluated.

Taxonomic revisions and corrections pertinent to the long-term data base were summarized and reviewed. Taxonomic revisions reflect recent taxonomic advances made in the scientific community, expansion of sampling efforts into oligohaline and tidal freshwater habitats, and errors that have been recognized and corrected. Natural history information on estuarine organisms was compiled from the literature to support the analysis and interpretation of the long-term data set, providing information on feeding type, mobility, sediment preference, time of reproduction, reproductive mode, type and duration of larval development, and life span.

The Quality Assurance/Quality Control (QA/QC) program is effective at identifying systematic errors and provides remedial procedures after errors are detected. These checks are required to assure that data are comparable among stations and sampling dates as well as with historical data. The QA/QC program also assures that data collected by this program are comparable to those collected by other elements of the Chesapeake Bay monitoring program. Systematic error rates are sufficiently high to suggest that the cost of the QA/QC program is justified, and we recommend that it be continued.

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I. INTRODUCTION

This report summarizes interim findings of an ongoing long-term benthic monitoring and assessment study for the Maryland portion of Chesapeake Bay. The study is jointly sponsored by the Maryland Department of the Environment (MDE), Water Management Division, and the Maryland Department of Natural Resources, Power Plant Research Program (PPRP) and is one element of an interdisciplinary Chesapeake Bay monitoring and assessment program. The primary goals for the first several years of the benthic program element are to:

- Identify and characterize major sources of variation in benthic populations and communities
- Determine the present status of benthic communities, including their relationship with natural and man-induced changes in environmental conditions (i.e., establish a baseline)
- Define the importance of benthic organisms in the functioning of the Chesapeake Bay ecosystem including their roles in nutrient cycling, sedimentation processes, and the food web.

This information will subsequently be used to:

- Evaluate the status of and trends in Bay benthic resources
- Determine the effectiveness of Bay-wide pollution abatement programs
- Measure the cumulative, long-term impacts of power plant operations on Bay benthic resources.

An evaluation of cumulative power plant impacts on Chesapeake Bay benthos will be completed in the spring of 1988. A preliminary determination of the "State-of-the-Bay" for benthos, and their functional role in Chesapeake Bay will also be completed in the spring of 1988. Evaluation of the effectiveness of pollution abatement measures will not be attempted until several years after major pollution abatement programs have been implemented.

This report does not directly address the long-term study objectives. It is an interim data report and includes a summary of biological and sediment data collected and processed through July 1987, and water quality data collected and processed through October 1987. Selected summaries of historic data for major regions of the Maryland Bay are also included. The specific objectives of this report are to:

- Summarize the first 3 years of data for water quality, sediment characteristics, and benthos populations and communities

- Describe Bay-wide spatial patterns of macrobenthos' identify environmental factors influencing regional distributional patterns, and accomplish a preliminary evaluation of the degree to which regional patterns vary from year to year

- Classify the Bay into strata based on water quality conditions and assemblages of macrobenthos

- Compare recent and historic benthic data for major regions of the Bay

- Develop an analysis approach that will systematically address long-term program objectives

- Evaluate the quality of the data being collected (Quality Assurance/Quality Control program)

- Determine if the benefits of the Quality Assurance/ Quality Control program justify its expense.

A. MARYLAND'S CHESAPEAKE BAY MONITORING AND ASSESSMENT PROGRAM

MDE, Water Management Division developed an interdisciplinary program to fulfill their responsibility for water quality monitoring and assessment activities in Maryland. The general goals of the monitoring and assessment program are to:

- Define existing conditions (i.e., characterize the "State-of-the-Bay")

- Identify processes and mechanisms controlling the Bay's water quality

- Define linkages between water quality and living resources

- Identify management and pollution abatement actions required to improved the health of the Bay

- Track the effectiveness of pollution abatement and resource management actions taken to improve water quality.

In addition to taking static measurements of water quality parameters, the MDE interdisciplinary monitoring and assessment program measures biological indicators of water quality. The biological indicators selected for study integrate water quality conditions over time periods of hours (plankton) to several years (benthos). The program also measures rate processes affecting water quality. The studies of biological indicators and rate processes, of which the combined MDE/PPRP benthic monitoring and assessment program is one element, provide information on processes and mechanisms affecting water quality which are not contained in static water quality measurements. Most importantly, inclusion of biological indicators in MDE's monitoring program provides a direct method for investigating the link between water quality conditions and the status of living resources. The various elements of MDE's Bay-wide monitoring program include the measurement of:

- Fall line inputs of nutrients, sediments, and selected toxic and hazardous substances
- Mainstem and tributary water quality
- Phytoplankton species abundance, biomass, and productivity in the mainstem Bay and selected tributaries
- Zooplankton abundance and biomass in the mainstem Bay and selected tributaries
- Benthic abundance, biomass, and productivity in the mainstem Bay and major tributaries
- Sediment characteristics in the mainstem Bay and major tributaries
- Sediment oxygen demand, nutrient flux, and water column metabolism in the mainstem Bay and selected tributaries
- Sedimentation rates at a representative mainstem Bay location
- Concentrations of toxic and hazardous substances in surface sediments at selected locations in the mainstem Bay and tributaries.

Sampling station locations for the various elements of the MDE monitoring and assessment program are shown in Fig. I-1.

B. THE BENTHIC PROGRAM ELEMENT

Benthic organisms are appropriate biological indicators of long-term changes in water quality. Most benthos have limited mobility and thus cannot avoid changes in environmental conditions resulting from power plant discharges or regional changes in water quality due to Bay-wide cleanup programs. Benthic assemblages are composed of diverse taxa with a mix of sizes, modes of reproduction, feeding guilds, life history characteristics, and physiological tolerances to environmental conditions. Therefore, they respond to changes in conditions, both natural and anthropogenic, in a variety of ways and are potentially sensitive indicators and integrators of environmental change. Changes in benthos populations and communities are thus probably the best available indicator of the net cumulative biological effects of changes in water quality (including those due to pollution abatement measures) and perturbations resulting from power plant operations.

Benthic organisms are also important to the overall "health" of Chesapeake Bay. They are major secondary producers and form "key" intermediate linkages between primary producers and higher trophic levels (Virnstein 1977, Holland et al. 1980). The burrowing, feeding, and metabolic activities of benthic organisms also have important effects on Chesapeake Bay oxygen, nutrient, carbon and mineral cycles (Kemp and Boynton 1981, Boynton et al. 1982, Officer et al. 1984). For example, benthic organisms have the capability of removing large quantities of particulate material from the water, effectively controlling excess phytoplankton productivity and high suspended sediment loads (Officer et al. 1982).

Measurement of benthos response to Bay-wide cleanup programs and long-term power plant effects requires hypothesis testing. Before rigorous or sensitive hypothesis testing can be conducted, however, sources of benthos variation and interactions among these sources must be identified, quantified and partitioned (Holland 1985). Otherwise, responses to pollution abatement and/or power plant operations may be obscured and go undetected. For example, year-to-year changes in benthos associated with natural salinity fluctuations could obscure measurement of responses to improvements in water quality resulting from Bay-wide cleanup programs. An analysis plan that partitions variation due to natural sources (and interactions among natural sources) is thus required before responses to cleanup programs or power plant effects can be rigorously quantified. The analysis plan for the long-term benthic program, which is designed to partition natural variation from man induced changes, is presented in Chapter II.

The broader the scale of spatial and temporal coverage, the greater the amount of variation that can be partitioned during the analysis phase. The broad spatial and temporal coverage of the combined MDE/PPRP long-term benthic monitoring and assessment program therefore has major advantages over separate but less intensive programs sponsored by each agency. In addition, the broad coverage is obtained at substantial cost savings in reduced vessel rental fees and labor. An additional strength of the joint MDE/PPRP benthic monitoring and assessment program is that by combining resources, the two agencies are able to intensively monitor regions of concern for both agencies (e.g., the Potomac, Patuxent, and Choptank Rivers, the upper Bay, and Baltimore Harbor) more effectively and systematically than they would by separate programs. The most important strength of the joint MDE/PPRP benthic monitoring and assessment program is that it allows the two agencies to combine historic and recent data on water quality parameters, living resources, and ecosystem processes into a single data set. This data set can then be used to define the responses of benthos to changes in water quality, both natural and man-induced, and assess the cumulative long-term power plant impacts on the Bay's benthic resources.

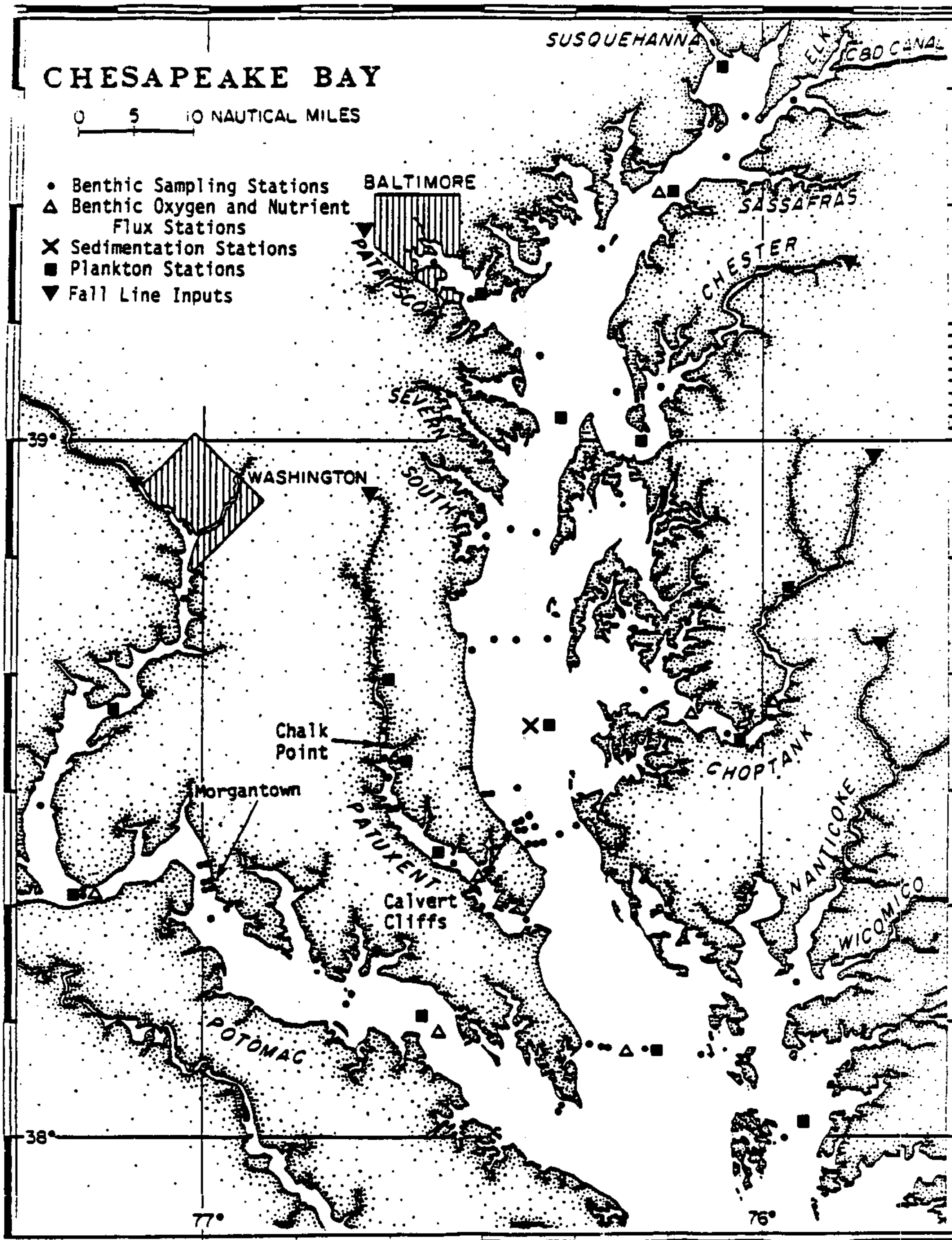

Figure I-1. Sampling locations for all program elements of MDE's Bay-wide monitoring and assessment program

II. LONG-TERM ANALYSIS APPROACH AND RATIONALE

The general analysis approach used by the benthic program element is to partition variation in benthic population and community parameters and in water quality parameters into spatial and temporal components in a manner that subdivides the study area into meaningful strata useful for the development and testing of hypotheses about:

- Responses of the benthos and water quality to pollution abatement
- Responses of the benthos and water quality to long-term power plant operations.

Both MDE and PPRP will use the empirical information and analysis results of this study in conjunction with information from other research and modelling studies to develop strategies and goals for water quality management, and impact evaluation and mitigation (Figs. II-1 and II-2).

The rationale for this scheme is summarized graphically in Fig. II-3. The specific steps are outlined in Fig. II-4. Steps A-C of Fig. III-4 were accomplished in previous work for PPRP or during preparation of the proposal for this project. The remaining steps along with their rationale are discussed in the following paragraphs. Portions of Steps D and E were accomplished in this report.

The first major analysis step (D in Fig. II-4) is to display and summarize the large amounts of data collected in a manner that will provide insights into its statistical properties. Summaries that are planned or have been completed include estimation of central tendency and dispersion, distribution form, and normality. An appraisal of normalizing and variance stabilizing transformations will also be made at this point in the program since many of the parametric hypothesis testing techniques to be applied later assume a normal distribution and stable variance.

Segmentation of the Bay into strata that aid in meaningful measurement of responses to pollution abatement and power plant effects is the objective of the second major analysis step (E in Fig. II-4). Without spatial stratification, it would not be possible to separate responses due to pollution abatement or power plant effects from natural variation (Fig. II-3). The segmentation scheme that is to be developed must be based on an understanding of the processes and mechanisms influencing the spatial distribution of benthos. It must also be compatible with planned pollution abatement actions, which are basin specific, as well as the segmentation schemes developed by other MDE monitoring program elements. Cluster analysis is a general analysis technique which we will use to identify spatial patterns and groupings (Boesch 1977b). Because cluster analysis is a multivariate technique, it will result in the identification of strata that reflect similarities and differences in the benthic community as a whole, when it is applied to the biological data. Identification of strata on the basis of physical and chemical parameters affecting the benthic habitat will be accomplished using principal components analysis (Gauch 1982). The final part of Step E is to combine the results of the physical/chemical and biotic segmentation schemes to identify physical/chemical parameters controlling regional distributional patterns. Once the major environmental factors controlling benthic distributions have been identified, variation associated with each will be partitioned in Step F.

Quantification of within year variation in benthic population parameters (i.e., quantification of average seasonal signals) is the objective of the next step in the analysis scheme (Step F in Fig. II-4). The within year stratification scheme must be based on life history information (e.g., timing of reproduction) and a knowledge of processes and mechanisms influencing benthic populations (i.e., regional distributional patterns). Trigonometric regression analysis will be the major technique used to characterize within year variation (Bliss 1967). This characterization will include estimation of the amplitude and phase of average seasonal fluctuations in benthic populations. Trigonometric regression will be applied as a part of ANCOVA that simultaneously partitions total variation into variation due to within year components and variance due to other identified sources (Holland 1985).

Based on information obtained in Steps A-F, the adequacy of the experimental design and sampling program will be determined (G in Fig. II-4). The evaluation is conducted at this point in the analysis plan because by then sufficient information will have been collected to permit a rigorous evaluation (18-24 months of data), and it is still early enough in the study to allow modification of the sampling program without loss of large amounts of information.

The measurement of benthic responses to pollution abatement or power plant operations requires hypothesis testing (Step H in Fig. II-4). Because of the high variance that is characteristic of benthic population parameters, hypothesis testing for responses to pollution abatement and power plant operations will be accomplished after partitioning variation due to seasonal patterns (trigonometric regression), environmental gradients (e.g., salinity, sediment characteristics), station effects (affected vs. unaffected; one region vs. others; reference vs. controls), year effects (before cleanup vs. during and after cleanup), and station-year interactions. ANCOVA is the major statistical method that will be used (Holland 1985).

The measurement of long-term trends in benthic populations will be accomplished after all identifiable sources of variation have been quantified and partitioned (second part of H in Fig. II-4). The major analysis method planned for the evaluation of long-term trends is linear regression of year means and residuals from previous ANCOVAs (Fig. II-4); however, non-parametric techniques that test for monotonic trends will also be applied. Trends for each of the spatial strata identified in Step D will be determined separately.

The final series of analyses (Steps I, J, K, and L in Fig. II-4) include extrapolation of population responses measured in the previous analyses to the entire benthic assemblage. Major questions to be addressed by these community level analyses include:

- Are pollution abatement or power plant effects favorable for some species and adverse for others?
- Are years that are favorable for some species adverse for others?
- Are community level responses to natural year-to-year changes in conditions, pollution abatement, and/or power plant effects similar for all regions of the Bay?

Analyses testing for community level responses to pollution abatement and power plant effects as well as characterizing long-term trends will include non-parametric tests (i.e., Friedman's Rank Sums Test, Conover 1971). Parametric multivariate statistical analyses may also be used to contrast benthic community properties among years by testing:

- A system of univariate hypotheses (e.g., MANOVA or MANCOVA with one hypothesis or trend for each species in the analysis, Cooley and Lohnes 1971)
- Hypotheses involving linear combinations of responses across species (e.g., Principal Components Analysis, Cooley and Lohnes 1971).

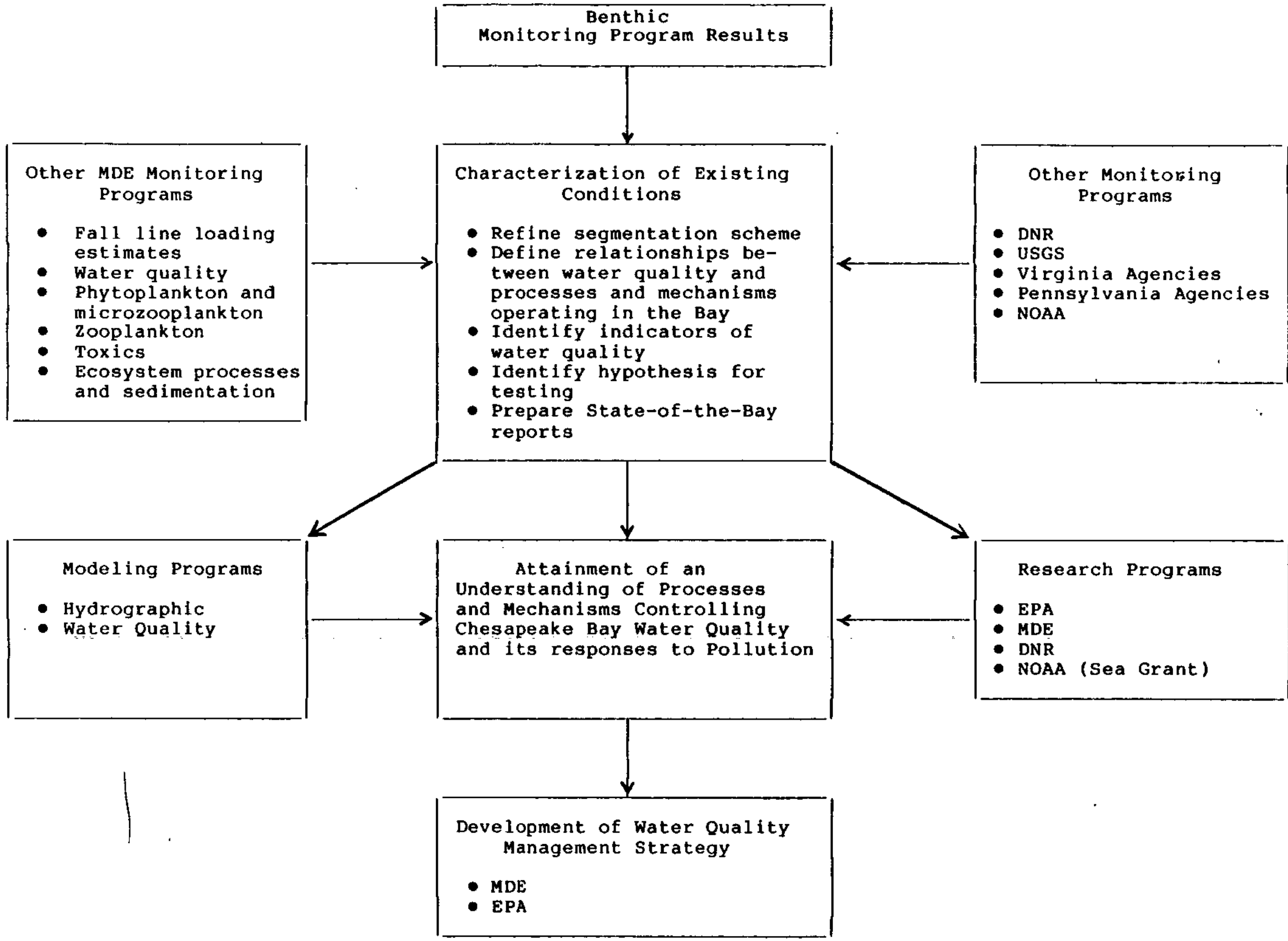

Figure II-1. Relationship of benthic monitoring program results to other MDE programs and attainment of the overall goal of development of a Chesapeake Bay water quality management strategy

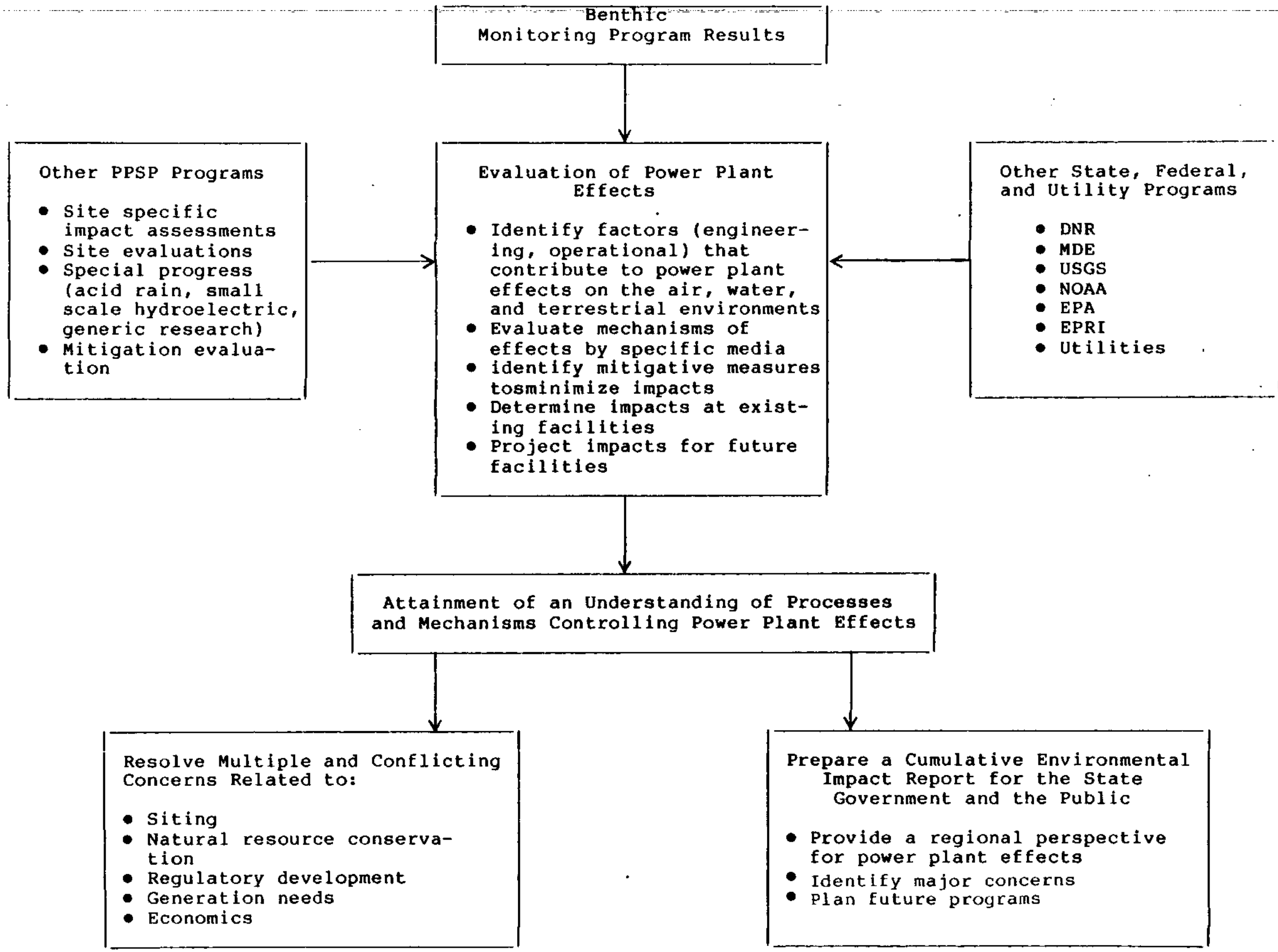

Figure II-2. Relationship of benthic monitoring program results to other PPRP programs and attainment of overall PPRP objectives

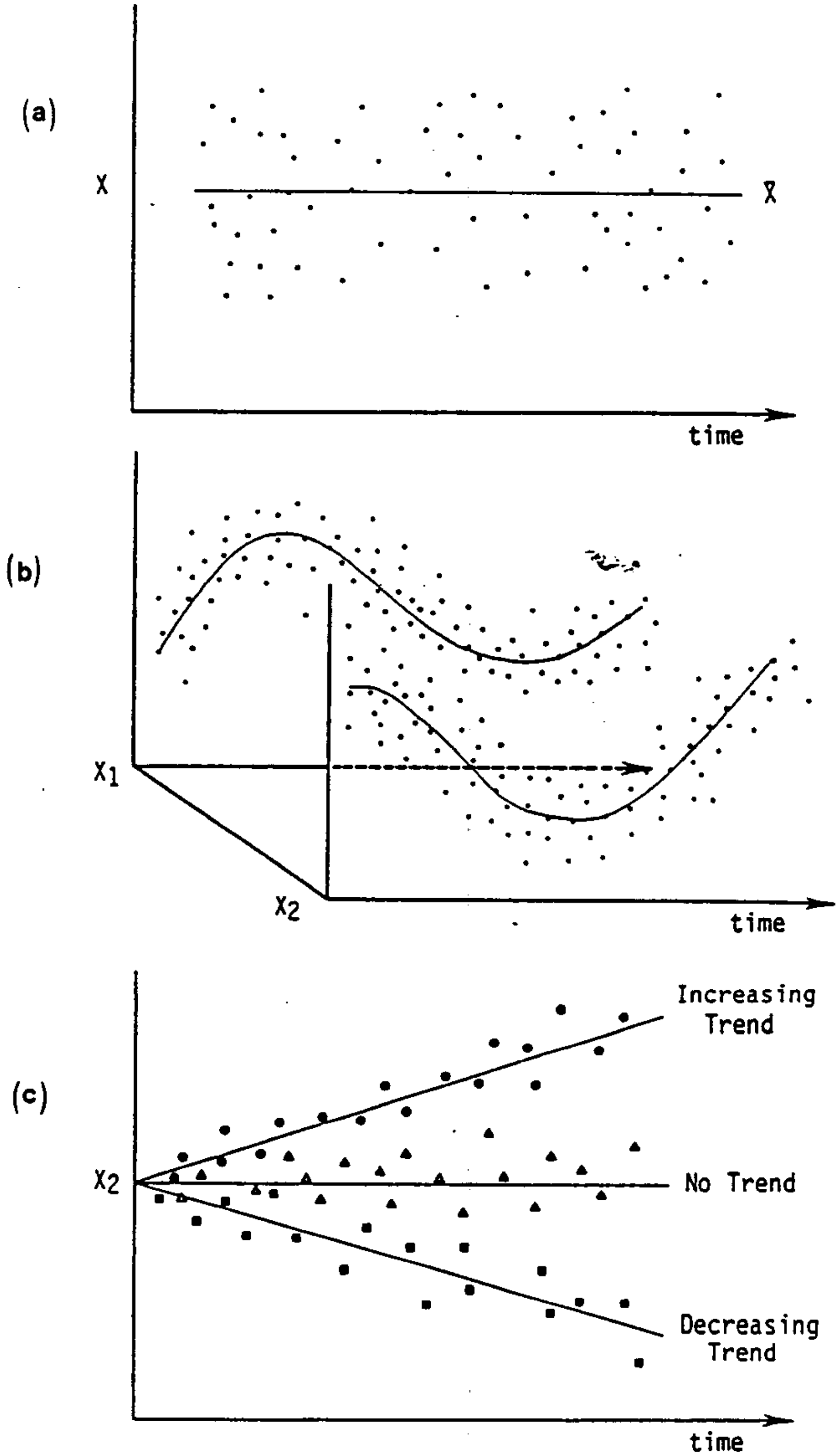

Figure II-3. Graphic summary of analysis approach: a) Data for parameter X lumped over all space and time, b) partitioning of spatial and short-term temporal patterns, and c) patterns remaining after accounting for spatial and short-term temporal variation (3 possible long-term trends)

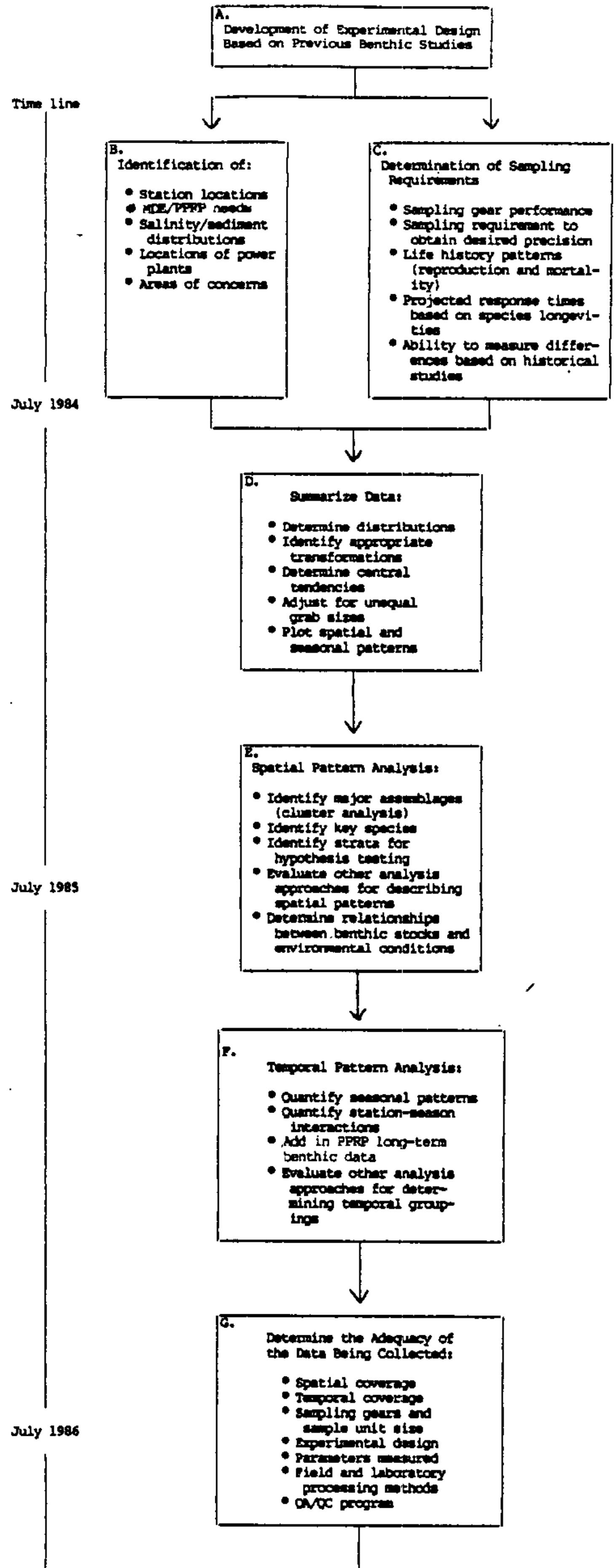

Figure II-4. Planned analysis scheme for the long-term benthic program element

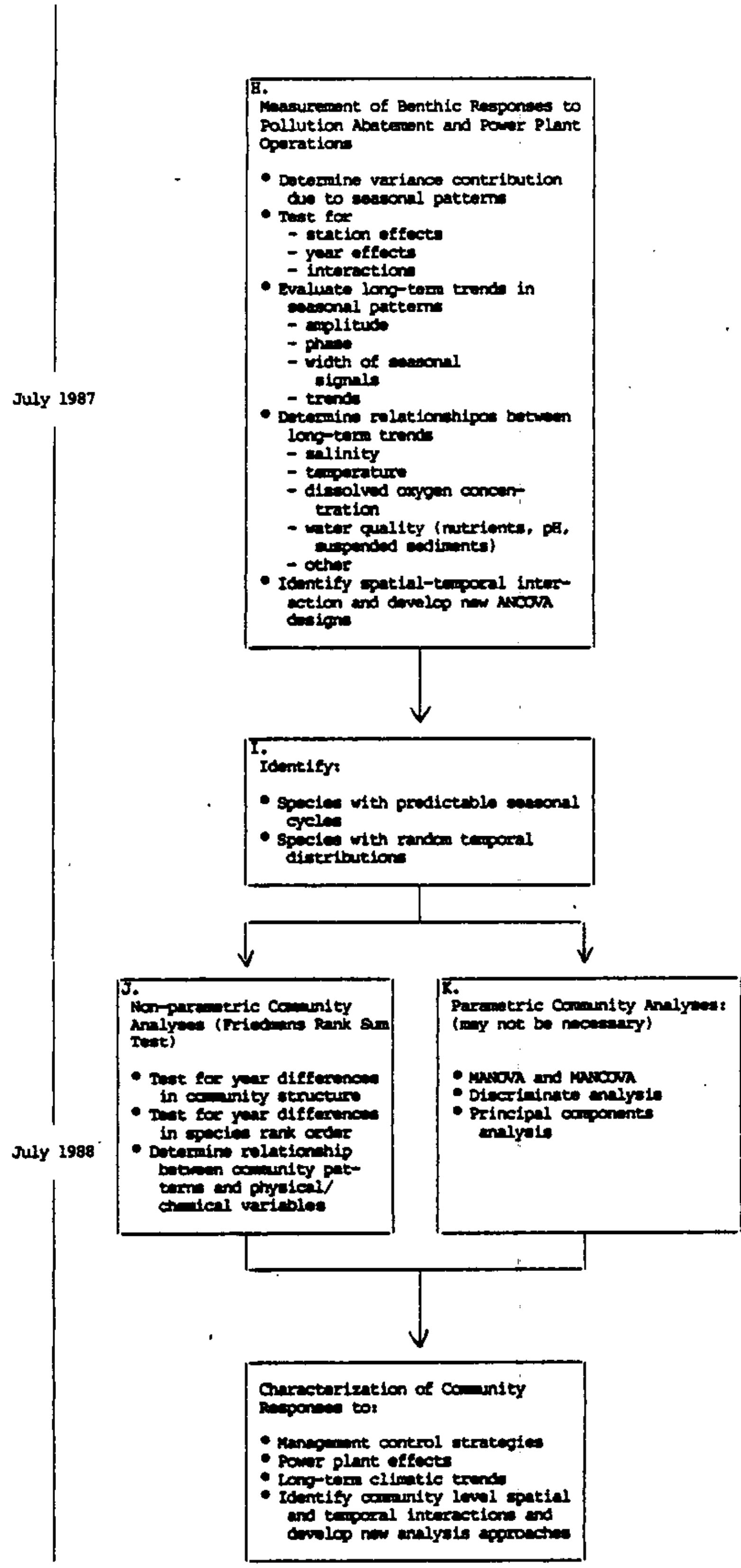

Figure II-4. Continued